AU04/1652

PA 1240916

THE UNITED STATES OF AMERICA

TO ALL TO WHOM THESE PRESENTS SHALL COME:

UNITED STATES DEPARTMENT OF COMMERCE

United States Patent and Trademark Office

October 28, 2004

THIS IS TO CERTIFY THAT ANNEXED HERETO IS A TRUE COPY FROM THE RECORDS OF THE UNITED STATES PATENT AND TRADEMARK OFFICE OF THOSE PAPERS OF THE BELOW IDENTIFIED PATENT APPLICATION THAT MET THE REQUIREMENTS TO BE GRANTED A FILING DATE UNDER 35 USC 111.

APPLICATION NUMBER: *60/525,405*
FILING DATE: *November 26, 2003*

By Authority of the

COMMISSIONER OF PATENTS AND TRADEMARKS

P. R. GRANT
Certifying Officer

Please type a plus sign (+) inside this box ⟶ [+]

PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a requ st for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No.

INVENTOR(S)

Given Name (first and middle [if any])	Family Name or Surname	Residence (City and either State or Foreign Country)
1. Michael	Berthon-Jones	NSW, Australia
2. Gordon	Malouf	NSW, Australia
3. Robert	Frater	NSW, Australia

[✓] Additional inventors are being named on the 1 separately numbered sheets attached hereto

TITLE OF THE INVENTION (280 characters max)

MACRO-CONTROL OF TREATMENT
FOR SLEEP DISORDERED BREATHING

Direct all correspondence to:

CORRESPONDENCE ADDRESS

[ ] Customer Number

⟶

Place Customer Number Bar Code Label here

OR

Type Customer Number here

[✓] Firm or Individual Name	Gottlieb, Rackman & Reisman, P.C.				
Address	270 Madison Avenue				
Address					
City	New York	State	NY	ZIP	10016-0601
Country	USA	Telephone	(212)684-3900	Fax	(212) 684-3999

ENCLOSED APPLICATION PARTS (check all that apply)

[✓] Specification   Number of Pages   16

[✓] Drawing(s)   Number of Sheets   8

[ ] Application Data Sheet. See 37 CFR 1.76

[ ] CD(s), Number

[✓] Other (specify)   return itemized postcard

METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT

[ ] Applicant claims small entity status. See 37 CFR 1.27.

[✓] A check or money order is enclosed to cover the filing fees

[ ] The Commissioner is hereby authorized to charge filing fees or credit any overpayment to Deposit Account Number: 07-1730

[ ] Payment by credit card. Form PTO-2038 is attached.

FILING FEE AMOUNT ($)

$160.00

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

[ ] No.

[ ] Yes, the name of the U.S. Government agency and the Government contract number are: _____

Respectfully submitted,

SIGNATURE _____

Date   11/26/03

TYPED or PRINTED NAME   Raymond B. Churchill, Jr.

TELEPHONE   (212)684-3900

REGISTRATION NO. (if appropriate)   44,617

Docket Number: 3869/032

USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

PROVISIONAL APPLICATION COVER SHEET
Additional Page

Docket Number	3869/032	Type a plus sign (+) inside this box →	[+]

INVENTOR(S)/APPLICANT(S)		
Given Name (first and middle [if any])	Family or Surname	Residence (City and either State or Foreign Country)
4. Peter Edward	Bateman	NSW, Australia
5. David	Bassin	NSW, Australia
6. Stephen	Farrugia	NSW, Australia

Number __1__ of __1__

WARNING: Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038.

MACRO-CONTROL OF TREATMENT
FOR SLEEP DISORDERED BREATHING

Field of the Invention

5   The invention relates to methods and apparatus for treating sleep disordered breathing. In particular, the invention relates to automatic adjusting of control parameters for apparatus used in the treatment of sleep disordered breathing.

10   **Background of the Invention**

Sullivan invented the treatment of Obstructive Sleep Apnea (OSA) with nasal Continuous Positive Airway Pressure (CPAP) (see US Patent 4,944,310). Diagnosis of OSA typically takes two nights in a sleep clinic. During a first night, the patient is
15   monitored to see whether the patient has OSA. During the second night, a range of nasal mask pressures are tested to determine an appropriate pressure setting for a CPAP device to keep the airway open. Once a pressure setting is determined, the patient is prescribed a CPAP device set to that pressure for subsequent home treatment. Because of limited places in sleep clinics, patients can typically wait up to two years
20   before they have the opportunity to be diagnosed. More recently, automatic devices have been developed which can diagnose and treat patients in their own homes, reducing the delay. Some automatic devices can increase and decrease the treatment pressure during the night in accordance with patient need.

US Patent 5,199,424 (Sullivan & Lynch) describes a device for monitoring
25   breathing during sleep and control of CPAP treatment that is patient controlled. In particular, the patent describes a CPAP apparatus including: a variable pressured air source and means to vary the air pressure delivered therefrom; a nose piece for sealed air communication with a patient's respiratory system; an air communication line from the air source to the nose piece; a sound transducer adapted to be in sound communication
30   with the patient's respiratory system; and a feedback system controlling the output pressure of the air source in response to an output from the transducer so as to increase the output air pressure from said air source, in response to detection of sound indicative of snoring, in accordance with a predefined procedure. The sound transducer, in its most general form, comprises a pressure transducer which, in addition to detecting
35   snoring sounds, can detect other respiratory parameters such as the rate of breathing, inhaled air flow volume, and inhaled air flow rate. Output air pressure from air source is

increased in response to one or more of these parameters in accordance with a pre-defined procedure.

US Patent 5,134,995 (Gruenke et al.) is said to describe an apparatus and method for facilitating the respiration of a patient for treating mixed and obstructive sleep

5 apnea and certain cardiovascular conditions, among others, by increasing nasal air pressure delivered to the patient's respiratory passages just prior to inhalation and by subsequently decreasing the pressure to ease exhalation effort. The preferred apparatus includes a patient-coupled gas delivery device for pressurizing the patient's nasal passages at a controllable pressure, and a controller coupled with the delivery device

10 having a pressure transducer for monitoring the nasal pressure and a micro-controller for selectively controlling the nasal pressure. In operation, the controller determines a point in the patient breathing cycle just prior to inhalation and initiates an increase in nasal pressure at that point in order to stimulate normal inhalation, and subsequently lowers the nasal pressure to ease exhalation efforts.

15 US Patent 5,203,343 (Axe et al.) is said to describe a method and device for controlling sleep disordered breathing utilizing variable pressure. The compressor supplies air at a relatively low pressure to the user's air passages while the user is asleep. A pressure transducer will monitor the pressure and convert the pressure into an electrical signal. The electrical signal is filtered and processed to compare it to the

20 characteristics of waveforms that exists during snoring. If the envelope of the waveform exceeds an average threshold value in duration and in area, then the microprocessor will consider the envelope possibly associated with a snore. If a selected number of envelopes of this nature occur within a selected time period, then the microprocessor considers snoring to exist and increases the pressure of the compressor. If snoring is

25 not detected within a certain time period, then the microprocessor lowers the level gradually.

US Patent 5,335,654 (Rapoport) is said to describe, in the treatment of obstructive sleep apnea, a CPAP flow generator employed to direct air to a nasal mask fitted to a patient. The airflow from the generator is monitored, and the flow and/or

30 pressure is increased when the waveform of the airflow exhibits characteristics corresponding to flow limitation. The generator may be controlled to repetitively test for waveform variations, in order to adjust the CPAP flow to the minimum level that does not produce flow limitation.

2

US Patent 5,704,345 (Berthon-Jones) describes a method and apparatus for detection of apnea and obstruction of the airway in the respiratory system. Methods and apparatus for determining the occurrence of an apnea, patency and/or partial obstruction of the airway are disclosed. Respiratory air flow from a patient is measured to give an

5   air flow signal. The determination of an apnea is performed by calculating the variance of the air flow signal over a moving time window and comparing the variance with a threshold value. One determination of partial obstruction of the airway is performed by detecting the inspiratory part of the air flow signal, scaling it to unity duration and area and calculating an index value of the amplitude of the scaled signal over a mid-portion.

10   Alternatively, the index value is a measure of the flatness of the air flow signal over the mid-portion. One determination of patency of the airway is performed by applying an oscillatory pressure waveform of known frequency to a patient's airway, calculating the magnitude of the component of said air flow signal at the known frequency induced by the oscillatory pressure waveform and comparing the calculated magnitude with a

15   threshold value. Alternatively, the air flow signal is analyzed to detect the presence of a component due to cardiogenic activity.

US Patent 6,367,474 (Berthon-Jones & Farrugia) describes CPAP treatment apparatus having a controllable flow generator operable to produce breathable gas at a treatment pressure elevated above atmosphere to a patient by a delivery tube coupled to

20   a mask having a connection with a patient's airway. A sensor generates a signal representative of patient respiratory flow that is provided to a controller. The controller is operable to determine the occurrence of an apnea from a reduction in respiratory airflow below a threshold, and if an apnea has occurred, to determine the duration of the apnea and to cause the flow generator to increase the treatment pressure by an amount which

25   is an increasing function of the duration of the apnea, and a decreasing function of the treatment pressure immediately before the apnea.

In general, these types of techniques of control of the administration of CPAP treatment can be regarded as "micro-control" algorithms. That is, they monitor the condition of the patient at any given moment. A variety of techniques for monitoring the

30   patient's condition may be used, including detecting flattening of the inspiratory flow-time curve, detecting a reduction in patient ventilation and detecting snoring. If there is an indication of sleep disordered breathing, the response is to increase the treatment pressure. Absent the indication of sleep disordered breathing, treatment pressure may

3

be decreased. A question of interest is how effective such algorithms are in treating OSA.

The Apnea-Hypopnea Index (AHI) provides a measure of the number of apneas and hypopneas which a patient experiences during sleep. The AHI is sometimes used

5 to assist in diagnosis of OSA. The AHI may also be used as an indication of the effectiveness of the nasal CPAP treatment. Hence at least one automatic CPAP device, AUTOSET T $_{TM}$, manufactured by ResMed Limited, reports the AHI, amongst other things, after a night's treatment. A problem with such an approach is that if the AHI indicates that therapy has been ineffective, the device may not be able to respond to

10 such a result without being adjusted by a technician or clinician.

Brief Description of the Invention

In accordance with a first aspect of the invention a method and apparatus for treating sleep disordered breathing is provided which automatically adjusts its sensitivity to indications of sleep disordered breathing.

15 In accordance with another aspect of the invention, a method and apparatus for treating sleep disordered breathing is provided which monitors a patient's sleep arousal and in accordance with such a measure of sleep arousal automatically adjusts how aggressively it responds to indications of sleep disordered breathing.

In accordance with another aspect of the invention, a method and apparatus for

20 treating sleep disordered breathing is provided in which the effectiveness of therapy is continuously monitored. Where there is an indication that therapy has not been effective, treatment pressure changes are accelerated. Where there is an indication that therapy has been effective, treatment pressure changes are decelerated.

In accordance with another aspect of the invention, in methods and apparatus

25 providing micro-control of sleep disordered breathing, a macro-control algorithm is provided which monitors the effectiveness of the micro-control algorithm and adjusts its operational parameters where they prove ineffective. Thus, a first detection control loop detects the effectiveness of a second detection control loop by examining the changing condition of the patient and then the first detection control loop adjusts the second

30 detection control loop to improve performance of the first control loop.

Brief Description of the Drawings

Fig. 1 shows an apparatus in accordance with the invention.

Fig. 2 shows a "micro-control" algorithm in accordance with an embodiment of the invention.

4

Fig. 3 shows a "macro-control" algorithm in accordance with an embodiment of the invention.

Fig. 4 is a graph of a flow v. time curve illustrating an event of sleep arousal.

Fig. 5 is a chart of information flow in one embodiment of a device for adjusting settings of a pressure delivery device in accordance with a function of sleep or respiratory arousal.

Fig. 6 illustrates one embodiment of the input of a controller for adjusting treatment pressure based on a sleep arousal index.

Fig. 7 shows a function for adjusting the aggressiveness of reductions in treatment pressure in accordance the measure of sleep arousal.

Fig. 8 is a function for adjusting the aggressiveness of increases in treatment pressure in accordance the measure of sleep arousal.

Fig. 9 depicts a function for adjusting the sensitivity of flow limitation detection in accordance a measure of sleep arousal.

Fig. 10 illustrates another function for adjusting the sensitivity of flow limitation detection in accordance a measure of sleep arousal.

Fig. 11 depicts a function for adjusting the sensitivity of flow limitation detection in accordance with a measure of treatment pressure.

Detailed Description of the Invention

Apparatus suitable for performing the invention is shown in Fig. 1. An impeller 1 is coupled to an electric motor 2 which is connected to a servo 3 and directed by a controller 4. The controller 4 includes a micro-processor, data storage, and memory programmed with algorithms in accordance with the invention. Thus, the controller or processor is configured and adapted to implement the methodology described in more detail herein and may include integrated chips, a memory and/or other instruction or data storage medium. Programmed instructions may be either coded on integrated chips in the memory of the device or may be loaded as software.

The impeller, motor and controller assembly form the blower. A mask 5 is connected to the blower via a flexible conduit 6. Various switches 7 and a display 8 are provided on the housing of the blower. A number of sensors are provided within the blower to monitor amongst other things, flow 10, pressure 11, snore 12, motor speed 13 and motor current 14. Various devices are known in the art that can serve as these types of sensors. A communications interface 15 is provided which allows data to be transferred between the apparatus and an external device, such as a computer or

controller. Whilst in a preferred form, a nasal mask S is shown, other forms of patient interface such as a nose & mouth mask or full-face mask may be used. Furthermore, while a variable speed motor is preferred, other means for providing a supply of breathable gas at positive pressure may be used, such as a constant speed motor with variable venting or a stepped-down piped pressure supply.

In accordance with the methods described in US Patent 5,704,345 (Berthon-Jones), the entire contents of which are hereby incorporated by cross-reference, in use, indications of sleep disordered breathing, or airway obstruction in the patient are monitored. For example, flow, pressure and snore sensors 10, 11, 12 monitor the shape of the inspiratory flow-time curve, patient ventilation and snore. A generally flattened inspiratory flow-time curve is taken as an indication of partial obstruction, as is the presence of snoring.

I. Obstruction Indicators

(a) Shape Factors

In one form, the shape of the flow-time curve is monitored as follows. The digitized flow signal is filtered to remove any leak component. Inspiratory and expiratory portions of each breath are then identified by a zero-crossing detector. A number of evenly spaced points (typically sixty-five), representing points in time, are interpolated by an interpolator along the inspiratory flow-time curve for each breath. The curve described by the points is then scaled by a scaler to have unity length (duration/period) and unity area to remove the effects of changing respiratory rate and depth.

Conveniently, the scaled breaths are compared in a comparator with a prestored template representing a normal unobstructed breath. The template is very similar to the curve for a normal inspiratory event. Breaths deviating from this template by more than a specified threshold (typically 1 scaled unit) at any time during the inspiratory event, such as those due to coughs, sighs, swallows and hiccups, as determined by a test element, are rejected.

For data not rejected by this test, a moving average of the first such scaled point is calculated by an arithmetic processor for the preceding several inspiratory events. This is repeated over the same inspiratory events for the second such point, and so on. Thus, sixty-five scaled data points are generated by the arithmetic processor, and represent a moving average of the preceding several inspiratory events. The moving average of continuously updated values of the sixty-five points are hereinafter called the

6

"scaled flow". Similarly, a single inspiratory event can be utilized rather than a moving average.

From the scaled flow two shape factors that directly relate to the determination of partial obstruction are calculated. Each shape factor equates to the Obstruction Index discussed above.

Shape factor 1 is the ratio of the mean of the middle thirty-two scaled flow points to the mean overall sixty-five scaled flow points. This is thus a determination of the reduction of the magnitude (depression) of the mid-portion of the scaled inspiratory event(s). Since the mean for all sixty-five points is unity, the division need not actually be performed.

For a normal inspiratory event this ratio will have an average value in excess of unity, because a normal such inspiratory event is of higher flow in the middle than elsewhere. Conversely, for a severely flow-limited breath, the ratio will be unity or less, because flow limitation occurs particularly during the middle half of the breath when the upper airway suction collapsing pressure is maximal. A ratio of 1.17 is typically taken as the threshold value between partially obstructed and unobstructed breathing, and equates to a degree of obstruction that would permit maintenance of adequate oxygenation in a typical user.

In other embodiments the number of sampled points, number of breaths and number of middle points can be varied, and still achieve a meaningful determination of whether partial obstruction is occurring. The threshold value similarly can be a value other than 1.17. Decreasing the threshold makes the device less sensitive to detecting obstruction. Increasing the threshold makes the device more sensitive to detecting obstruction.

Alternatively, the second shape factor is calculated as the RMS deviation from unit scaled flow, taken over the middle thirty-two points. This is essentially a measure of the flatness of the midportion of the scaled respiratory event(s). For a totally flow-limited breath, the flow amplitude vs. time curve would be a square wave and the RMS deviation would be zero. For a normal breath, the RMS deviation is approximately 0.2 units, and this deviation decreases as the flow limitation becomes more severe. A threshold value of 0.15 units is typically used. Decreasing the threshold makes the device less sensitive to detecting obstruction. Increasing the threshold makes the device more sensitive to obstruction.

7

Optionally, the shape factor may be determined by weighting certain portions of the flow signal as disclosed in U.S. Patent Application no. 09/924,325, filed on August 8, 2001, the entire disclosure of which is hereby incorporated by reference.

Both shape factors discussed above can be utilized independently in
5   implementing the methodology carried by the apparatus, and result in the sensitive and reliable detection of partially obstructed breathing. Better performance again is obtained by implementing both shape factors executed by the controller so that both shape parameters act together. In this case, shape factor 2 is preferred for use to detect all but the most severe obstructions, and shape factor 1 therefore is preferred for detecting only
10   the most severe obstructions, achieved by reducing the critical threshold from 1.17 to 1.0.

The two shape factors may operate in concert. The scaled flow signal is provided to a shape detector. The shape detector generates shape factor 1 and shape factor 2. Shape factor 1 is applied to a decision block and compared against the
15   threshold value of 1.0. If the outcome of the comparison is "Yes", then it is determined that there should be an increase in the CPAP pressure setting. The shape factor 2 is provided to the decision block, and a comparison made against a threshold value of 0.15. If the answer is "Yes", then it also is appropriate for an increase in the CPAP pressure.

20   In either case, if the results of the comparison is "No", then those results are ANDed in an AND gate. That is, an output will only be achieved, if both threshold criteria are not satisfied. In this case, there is no partial obstruction, or partial obstruction has subsided, in which case, it is appropriate to decrease the CPAP pressure.

This arrangement avoids any peculiarities affecting either algorithm. For
25   example, the presence of an initial non-flow-limited period early in a breath can permit an early sharp peak in the flow-time curve. This means that the scaled flow during the middle half of the breath may be below unity. For very severely obstructive breaths, the RMS deviation from unity may therefore rise again, and shape factor 2 will fail to recognize such breaths. They will, however, be correctly identified by the now
30   desensitized shape factor 1. Some normal breaths can involve an inspiratory flow-time waveform approximating a right triangle, where the mean flow during the middle half of inspiration is close to unity. Such a waveform correctly triggers neither shape factor 1 nor shape factor 2. That is, the instantaneous flow during the middle half of the

8

inspiration is only unity at a single point, and above or below unity elsewhere, so the RMS deviation from unit scaled flow will be large.

In one form, a new shape factor is calculated for the inspiratory portion of each breath. In another form, a shape factor is calculated from the inspiratory portion of two or more breaths. Changing the number of breaths used in the calculation of a shape factor changes the sensitivity of the device. Including fewer breaths makes the device more sensitive to indications of partial obstruction.

Once a determination has been made that there is an indication of partial obstruction, the treatment pressure may be increased. For example, when shape factor 1 is below 1.0, the CPAP pressure is increased in proportion to the amount of the ratio being below 1.0. For example, the difference between the shape factor and the threshold may be multiplied by some gain to derive the change in pressure. In one form, an increase of 1 cm H_2O per breath per unit below a ratio of 1.0 is used. Conversely, if the ratio is above 1.0, indicating an absence of partial obstruction, the CPAP pressure is gradually reduced with a time constant of 20 minutes. If shape factor 2 is below 0.2, the CPAP pressure is increased at a rate of 1 cm H_2O per breath per unit below 0.2. Conversely, if the shape factor is above 0.2 units, the pressure is gradually lowered with a time constant of 20 minutes. The amount of the increase or decrease in pressure in the presence or absence of an indication of partial obstruction defines in part how aggressively the algorithm adapts its treatment.

Those skilled in the art will recognize other methods for detecting flow limitation, for example, by comparing a roundness index and a threshold, which may also be controlled to increase or decrease sensitivity in detection.

(b) Snore detection

As previously mentioned, detecting snoring can be an indicator of obstruction in the patient's airway. If a snore is detected by a snore detector (such as that disclosed in U.S. Patent 5,245,995, the entire contents of which are incorporated by cross reference) the mask pressure is also increased. If the snore index on the given breath exceeds a critical threshold value, the pressure is increased by 1 cm H_2O per unit above the threshold value.

Increasing the amount by which the pressure is increased makes the device treat more aggressively. The default threshold for the snore index is 0.2 units, corresponding approximately to a snore that can only just be reliably detected by a technician standing at the bedside. Increasing the snore threshold makes the device less sensitive. In one

9

form, the rate of rise in pressure is limited to a maximum of 0.2 cm H_2O per second, or 12 cm H_2O per minute. Conversely, decreasing the snore threshold makes the device more sensitive.

II. Index of Respiratory Effort Related Arousal or Sleep Arousal

5   To monitor the effectiveness of the device in treating sleep disordered breathing, an index of sleep arousal or a respiratory effort related arousal is calculated. In one form, this is calculated from the size of a patient's breath. The size of a patient's breath can be determined by monitoring the flow rate of air with time and integrating to calculate volumes. If a patient exhibits a run or sequence of breaths of a first size followed by a

10   larger breath, this is an indication that they are being aroused from sleep because of inadequate treatment and that more aggressive therapy may be required. For example, a run or sequence of 8 small breaths followed by a large breath can be an indicator that the patient is being aroused from sleep. In one form, a breath would be considered "large" if it was more than twice as large as previous breaths or small breaths. Breaths

15   would be considered "small" if they were less than the average minute ventilation. Whilst in a preferred form, it is only necessary to monitor patient respiration, other indices of sleep arousal may be used, for example, sensors which determine indications of sympathetic nervous system activity such as sweating and heart rate.

In an alternative embodiment, arousal from sleep may be determined by

20   detecting a post apnea sigh or yawn. This may be accomplished by a CPAP apparatus. For example, respiratory airflow is monitored to detect a breathing sequence including a degree of flattening or obstruction in a breath followed by a large breath. The flattening or obstruction may be, for example, a minor or subtle degree of flattening that might not even be considered sufficient to increase the CPAP pressure, and may be detected

25   using the shape factors previously described with a very sensitive threshold. The "large" breath may be considered "large" if it is absolutely a large breath of a predetermined quantity or more simply if it is relatively larger than other breaths of the patient such as one or more of those immediately preceding the large breath, which may be determined from volume. For example, the inspiratory portion or a respiratory airflow signal may be

30   integrated on a breath by breath basis. One such a detectable condition is illustrated in Fig. 4. In the figure, the detection of sleep arousal may be based on the detection of breath n followed by the flow limited breath n-1 or several, such as breaths n-1 and n-2.

In one embodiment, the detection of a respiratory effort related arousal may be estimated by examining respiratory irregularities with a short term moving average

measure of ventilation from data or a signal from the flow sensor. Peaks or other significant or relative increases in the measure are indicative of arousal events. The short term moving average can be determined by integrating a low pass filtered respiratory airflow signal with a time constant chosen for this purpose.

5   II. Overall Control Based on Sleep Arousal Detection

An overall or "macro-control" algorithm in accordance with the invention makes a determination of how aggressively to treat the patient based on a determination of whether they are being successfully treated and then adjusts the parameter values of the "micro-control" loop accordingly. Patients who are becoming aroused from sleep are

10   treated more aggressively. Patient's who are not being aroused from sleep are treated less aggressively. Similarly, based on the assessment of the success of the treatment, the algorithm can adjust the sensitivity of the obstruction detection routine to increase sensitivity for less successful treatment.

In one form, the device starts treating the patient using default settings for

15   parameter values, for example, a threshold value, but monitors sleep arousal during the course of the night. At the end of the night's treatment, representative parameter values are stored in a memory and on subsequent treatment nights, the representative parameter values from the previous treatment session are used at the beginning of treatment.

20   In one form, if a determination that the patient is being aroused from sleep has been made, the number of breaths which are averaged to determine a shape index is reduced. If that is insufficient to achieve an improvement in the patient, then the threshold level necessary to initiate an increase in treatment pressure is adjusted, making the device more sensitive.

25   In another form, the time constant of decay of treatment pressure is increased if treatment determined to be ineffective base on the arousal index. In this way, the pressure stays high for longer following an increase which has resulted from the detection of an indication of partial obstruction.

Optionally, the apparatus may be configured to increase the treatment pressure

30   in response to the detection of an event of sleep arousal or respiratory effort related arousal in accordance with one of the previously described arousal indices. For example, pressure may be increased by a certain unit of pressure for each detected event of arousal up to a maximum pressure. Similarly, the pressure may be reduced towards a minimum support pressure in the absence of arousal events over period of

11

time, such as one hour. As an alternative, data associated with one or more breathing cycles immediately preceding the breath indicative of the sleep arousal may be subsequently analyzed by the apparatus to determine a proportional amount of treatment pressure change that would be appropriate to compensate for the respiratory

5   related event. Thus, additional or supplemental analysis may be triggered by the detection of the sleep arousal. For example, the prior breaths may be re-analyzed by one of the shape factors or obstruction detectors discussed above with thresholds of greater sensitivity than they were previously subjected to as discussed herein. With the new analysis, a calculated proportional amount of pressure change may be generated

10 based on the detection of the flow limitation if such flow limitation had not previously been detected for the particular breath. In this embodiment, flow signal related data from previous breaths can be stored in memory for the re-analysis.

In one embodiment of the apparatus, the control methodology will default to keep the pressure low (4 cmH$_2$O) while the patient is awake but will increase pressure with

15 sleep onset. Methods for doing so are known in the art. The device then detects the presence of respiratory related event arousals or sleep arousals preferably after a period of time over which the patient may fall asleep. In one form the device will then monitor flow to detect a short, sudden period of flow limitation, terminated by a big breath, which will be indicative of a respiratory arousal. If it detects such a sleep arousal, it will

20 become (1) more sensitive to detecting obstructive or other SDB events, for example by making adjustments to detection thresholds, (2) more rapid or aggressive in its pressure response to these events, for example by increasing the pressure gain used in response to each event, and (3) more reluctant to again lower the pressure when arousal events have stabilized or discontinue.

25 For subsequent sleep arousals (representing patients intermediate between the stable and unstable ends of the spectrum) the above process is repeated, so that after about 2 arousals or some near number, the device will adjust itself to treat, with greatly increased rate of response, and once an optimal pressure is found, to maintain that optimal pressure for an hour or so.

30 Preferably if further respiratory arousals are detected (representing the most unstable, arousable, currently poorly treated extreme of the spectrum) the device remains indefinitely at a therapeutic pressure. Thus the device would have become essentially a fixed CPAP device, with automatic detection of sleep onset. Optionally, in the next day of treatment, the device can revert either to its default behavior as

12

previously described, or it can resume to a larger or smaller degree the sensitivity of detection, aggressiveness (more rapid) treatment pressure response, or more persistent in maintaining a higher pressure by using the settings arrived at during the prior session.

A methodology/apparatus for sleep arousal-based control in the treatment of

5   SDB is illustrated in Figures 5 and 6. As shown in Fig. 5, an obstruction and/or a snore detector derive an obstruction index and/or a snore index from respiratory airflow. A respiratory effort related arousal or sleep arousal detector derives a sleep arousal index from an obstruction index or snore index and respiratory airflow. The obstruction and/or snore index and the sleep arousal index are then utilized in deriving a pressure setting

10   by a pressure determination device. Fig. 6 depicts the pressure determination device of Fig. 5. As depicted in Fig. 6, the respiratory effort related arousal/sleep arousal index is applied to adjust the thresholds compared with the obstruction/snore indices. The sleep arousal index is also applied to adjust the gain to change the aggressiveness of pressure increases. Finally, the sleep arousal index is also applied to adjust the

15   recovery time constant of the treatment pressure to delay the pressure decay after an SDB event has subsided. In other words, a higher respiratory arousal index renders a more sensitive obstruction/snore detection, a more aggressive pressure increase in response to detected events and a prolonged period of pressure treatment to an SDB event.

20   (a) Sleep Arousal based Gain adjustment

As previously noted, in response to detected sleep arousal(s) the pressure response made to detected SDB events, the pressure response of the apparatus may be modified to generate more aggressive increases and/or less aggressive decreases in pressure. Various functions can provide these adjustments as a function of an index of

25   detected sleep arousals. For example, the aggressiveness of pressure withdrawal (i.e. a less aggressive decrease) can be accomplished with the following formula which may serve as the pressure change when there is no detected obstruction that would require an increase in pressure.

$$\Delta P = -K(P - P_{min}) \qquad \text{when } S > S_T$$

30   where:

ΔP is the pressure adjustment or the pressure change;

K is a function of the detected sleep arousal;

P is the actual pressure being delivered to the patient;

P_{min} is a desired minimum pressure level;

13

S is an obstruction index such as flow flattening or snore index;

S_T is a threshold value for the obstruction index;

Various functions of sleep arousal K may be devised. For example, one such function may be based on the number of detected sleep arousals with K decreasing with

5 an increasing number of detected events to a maximum. Such a function is illustrated in FIG. 7. The selection of the number of arousals and maximum value of K may be based on clinical experimentation and would be within the skills of individuals in the field. As shown, the number of arousals may be based on a function of time, for example, a per hour basis using the number of events from the immediately preceding hour. In an

10 alternative embodiment, the function may be based on the number of sleep arousals in a particular session with the device, for example, during a single night. In the example formula shown, as the pressure decreases after obstruction is no longer found, pressure will decrease more slowly as the number of sleep arousals detected approaches 15 events in the previous hour. Thus, the decay in treatment pressure as a result of the

15 above function will tend to be exponential approaching the minimum pressure for few or no detected events but will decay less rapidly as a greater number of events are detected. As shown, exceeding a certain number of such detections can prevent the device from withdrawing treatment as the K approaches 0 near a chosen critical number of sleep arousal events.

20 Conversely, when the shape detector/snore index indicates that there is an SDB event that must be treated by comparing a detected index to a threshold, the treatment pressure will be increased as a function of some gain. However, in an embodiment of the invention, the gain affecting the rate of the pressure increase is a function of sleep arousal. One such gain may be utilized to deliver treatment pressure in accordance with

25 the following formula:

$$\Delta P = G(S - S_T) \qquad \text{when } S < S_T$$

where

ΔP is the pressure adjustment or the pressure change;

G is a function of the detected sleep arousal;

30 S is an obstruction index such as flow flattening or snore index;

S_T is a threshold value for the obstruction index;

For example, an exponential function for G may be utilized to increase the gain as an increasing function of a cumulative number of detected sleep arousal events. One such function is illustrated in the graph of Fig. 8. In the graph shown, if no events of sleep

arousal are detected or if none are detected after a certain period of time, for example, none in the immediately preceding hour, the gain remains at a typical gain. However, as the number of these detected events accumulates, the gain will be increased, preferably as an exponential function approaching some maximum or higher gain. Of course, as

5   the number of detected sleep arousal events decreases, the gain will be reduced according to the chosen graph of the sleep arousal function.

While the exponential function is shown, those skilled in the art will recognize that other functions for increasing the gain as a function of an increasing number of detected sleep arousal events can be utilized, for example, a linear or other ramp function.

10   (b) Sleep Arousal based Threshold Adjustment

As previously mentioned, an adjustment or change to the sensitivity of the apparatus may be implemented by changing obstruction response thresholds as a function of an index of sleep arousals. Those skilled in the art will recognize that a change by either an increase or decrease in the threshold amount may be associated

15   with either an increase or decrease in sensitivity. This relationship is attributable to the nature of the particular obstruction index and its threshold as described previously. Some suitable functions relating to the methods disclosed herein are illustrated in the graphs of Figs. 9 and 10. In the illustrated example graph of Fig. 9, as the number of detected events increases over a period of time, such as the immediately preceding

20   hour, the threshold will be a decreasing function, such as a ramp, from a less sensitive to a more sensitive value. For example, for adjustment to the snore threshold as discussed above, when no sleep arousal events are detected, the snore threshold may remain at its default of about 0.2 units. However, as the number of arousal events increases, the threshold may be reduced according to a ramp or linear function to a

25   lower threshold rendering the detection of snoring related obstructive events more likely (increasing sensitivity).

The sample graph of Fig. 10 may be utilized to adjust or change the sensitivity of the shape factors discussed previously. As illustrated, a default threshold may remain constant in the absence of detected sleep arousal events. However, as the detected

30   number of sleep arousals increases, the shape factor threshold will increase rendering the detection of obstructive events more likely (more sensitive) which in turn will result in a greater likelihood of an increase in pressure treatment to address the detected obstruction events. Those skilled in the art will recognize that other functions of the

15

sleep arousal index may be utilized to change the sensitivity of various obstruction thresholds.

Similarly, the threshold may also be a function of treatment pressure. One such function is illustrated in Fig. 11 as it relates to shape factor 2 discussed previously. In the example, the threshold is held at a default value of 0.15 until treatment pressure exceeds 10 cm H_2O. The threshold decreases approaching 0 as the treatment pressure approaches 20 cm H_2O.

While the invention has been described with various alternative embodiments and features, it is to be understood that the embodiments and features are merely illustrative of the principles of the invention. Those skilled in the art would understand that other variations can be made without departing with the spirit and scope of the invention.
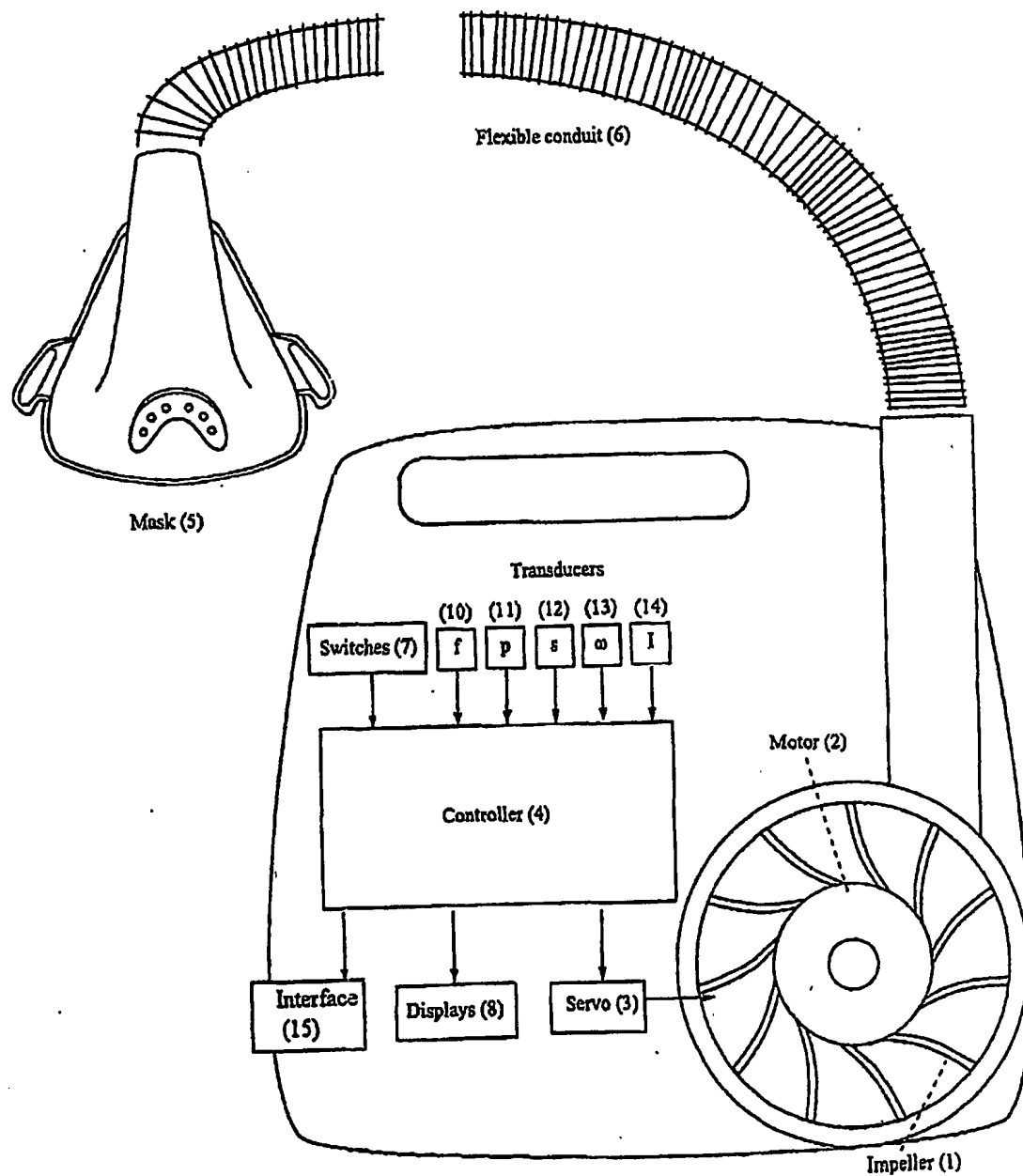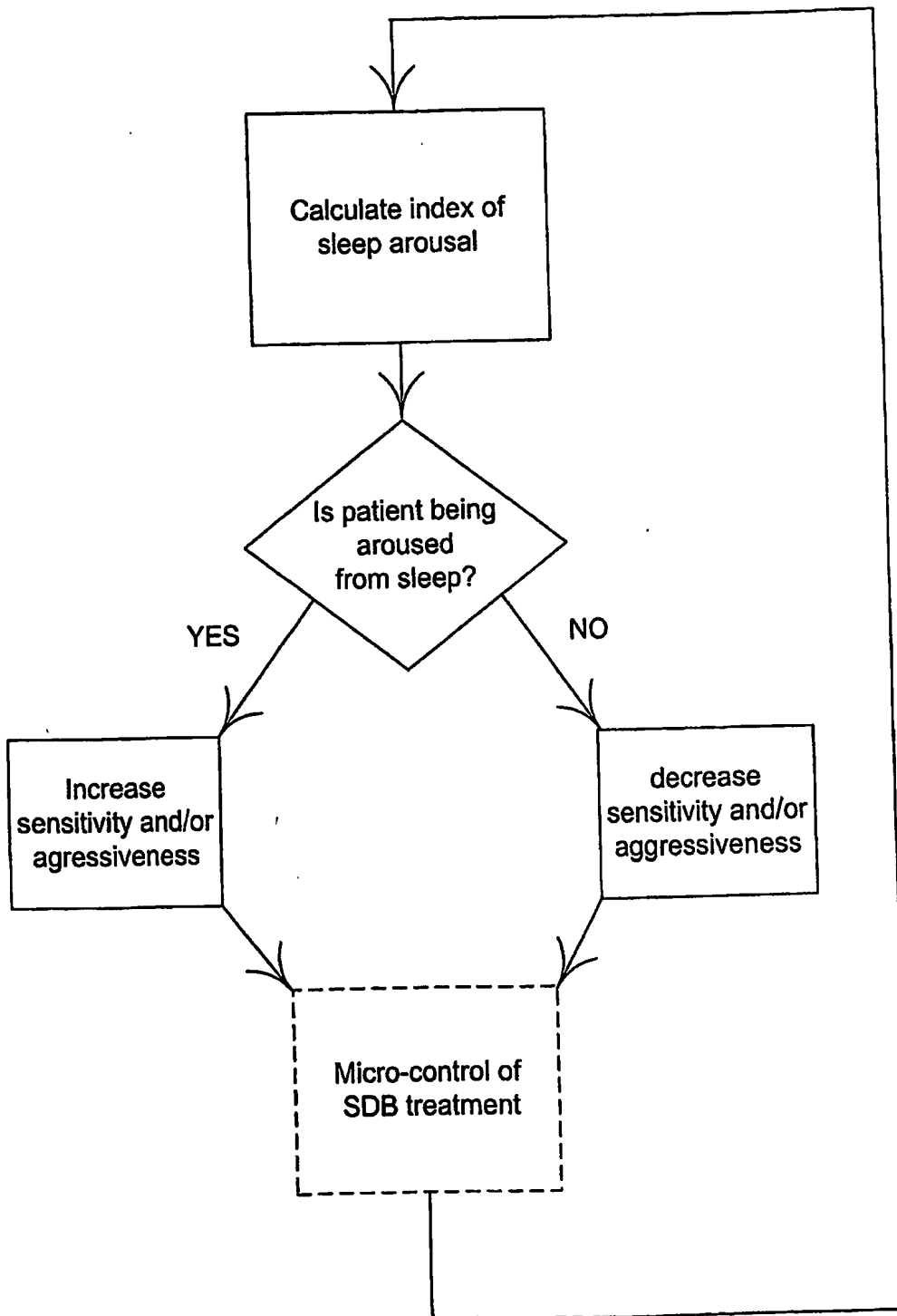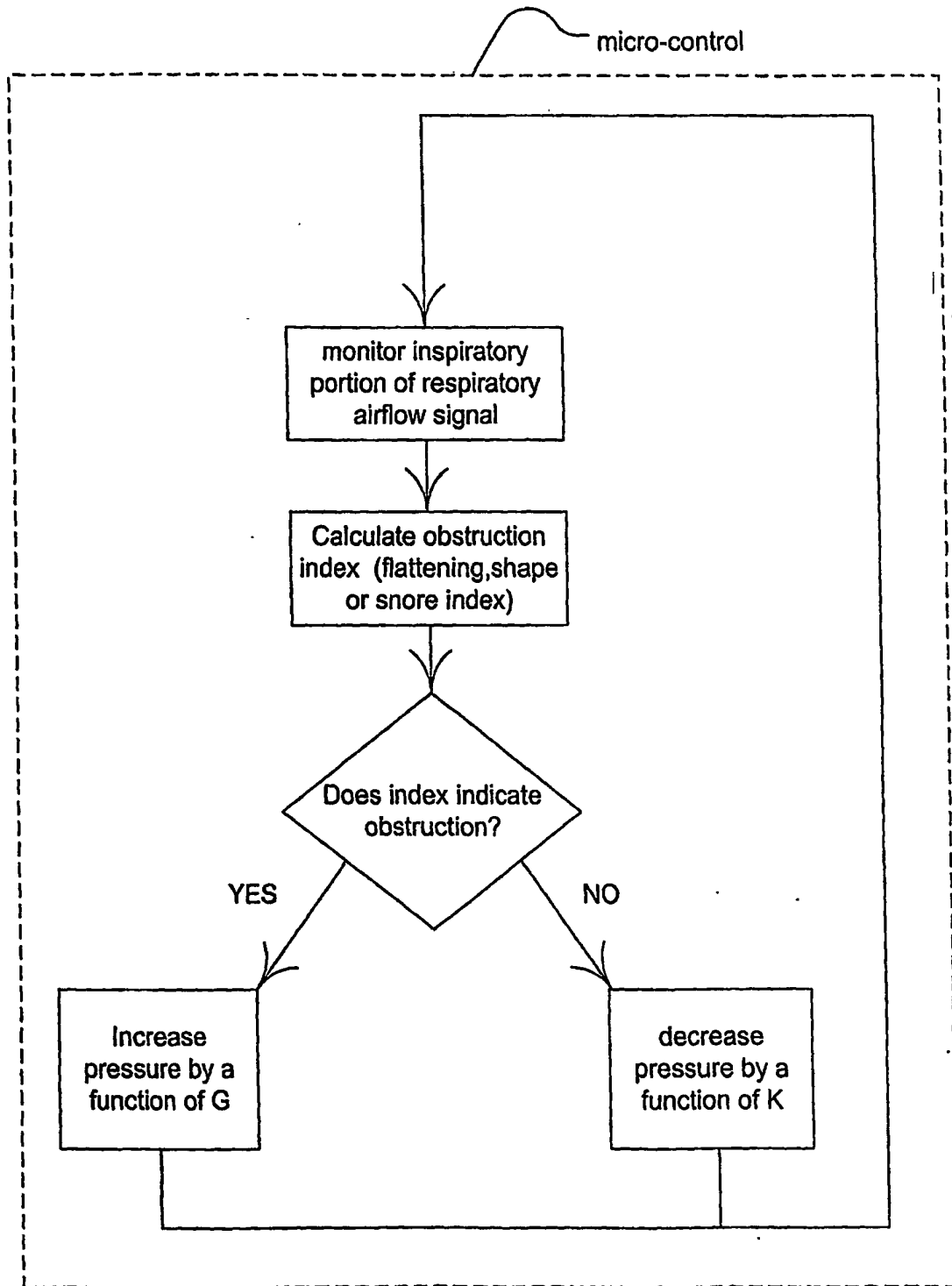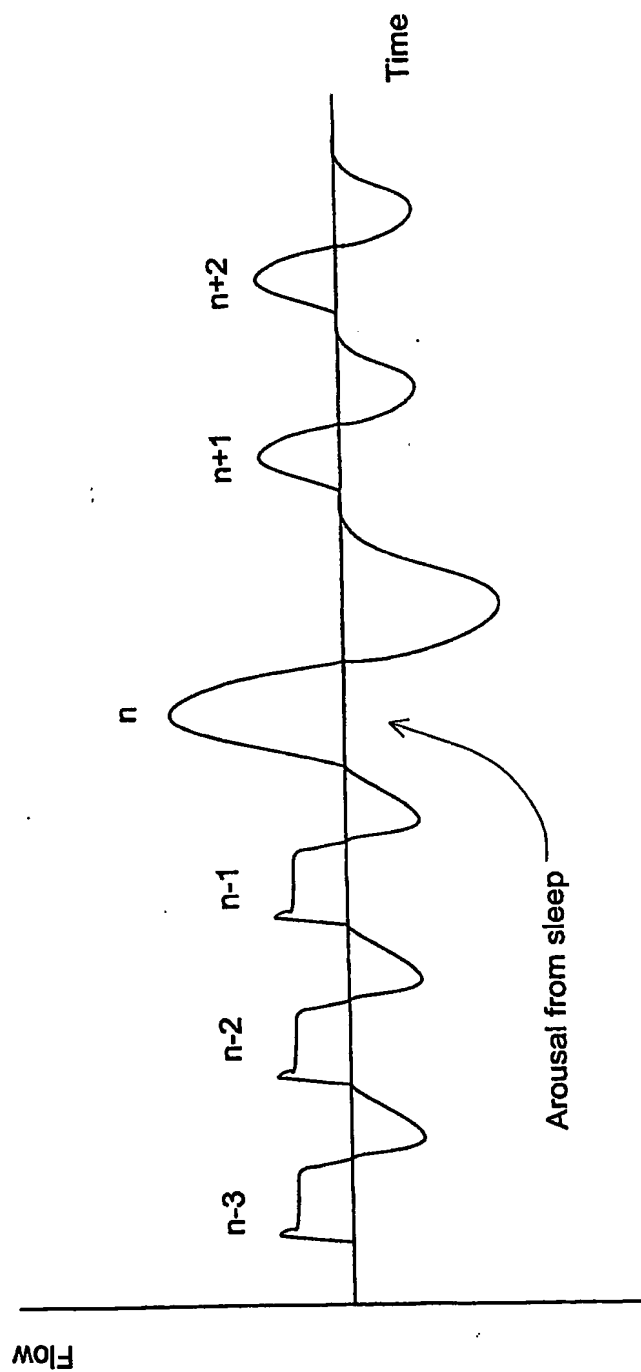
Figure 1: CPAP apparatus

FIG. 2

```
                    ┌─────────────────────┐
                    │                     │
                    │   Calculate index   │
                    │      of sleep       │
                    │      arousal        │
                    │                     │
                    └─────────────────────┘
                               │
                               ▼
                          ╱─────────╲
                        ╱   Is patient  ╲
                      ╱    being aroused   ╲
                      ╲    from sleep?     ╱
                        ╲               ╱
                          ╲─────────╱
              YES        ╱           ╲        NO
                        ▼             ▼
        ┌──────────────┐               ┌──────────────┐
        │  Increase    │               │  decrease    │
        │ sensitivity  │               │ sensitivity  │
        │  and/or      │               │  and/or      │
        │aggressiveness│               │aggressiveness│
        └──────────────┘               └──────────────┘
                    ╲                   ╱
                     ▼                 ▼
                  ┌ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┐
                  │                     
                  │  Micro-control of   │
                     SDB treatment      
                  │                     │
                  └ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┘
```

FIG. 3

micro-control

monitor inspiratory
portion of respiratory
airflow signal

Calculate obstruction
index (flattening,shape
or snore index)

Does index indicate
obstruction?

YES

NO

Increase
pressure by a
function of G

decrease
pressure by a
function of K

n-3   n-2   n-1   n   n+1   n+2

Arousal from sleep

Flow

Time

Detect flattened breath (n-1) folllowed by
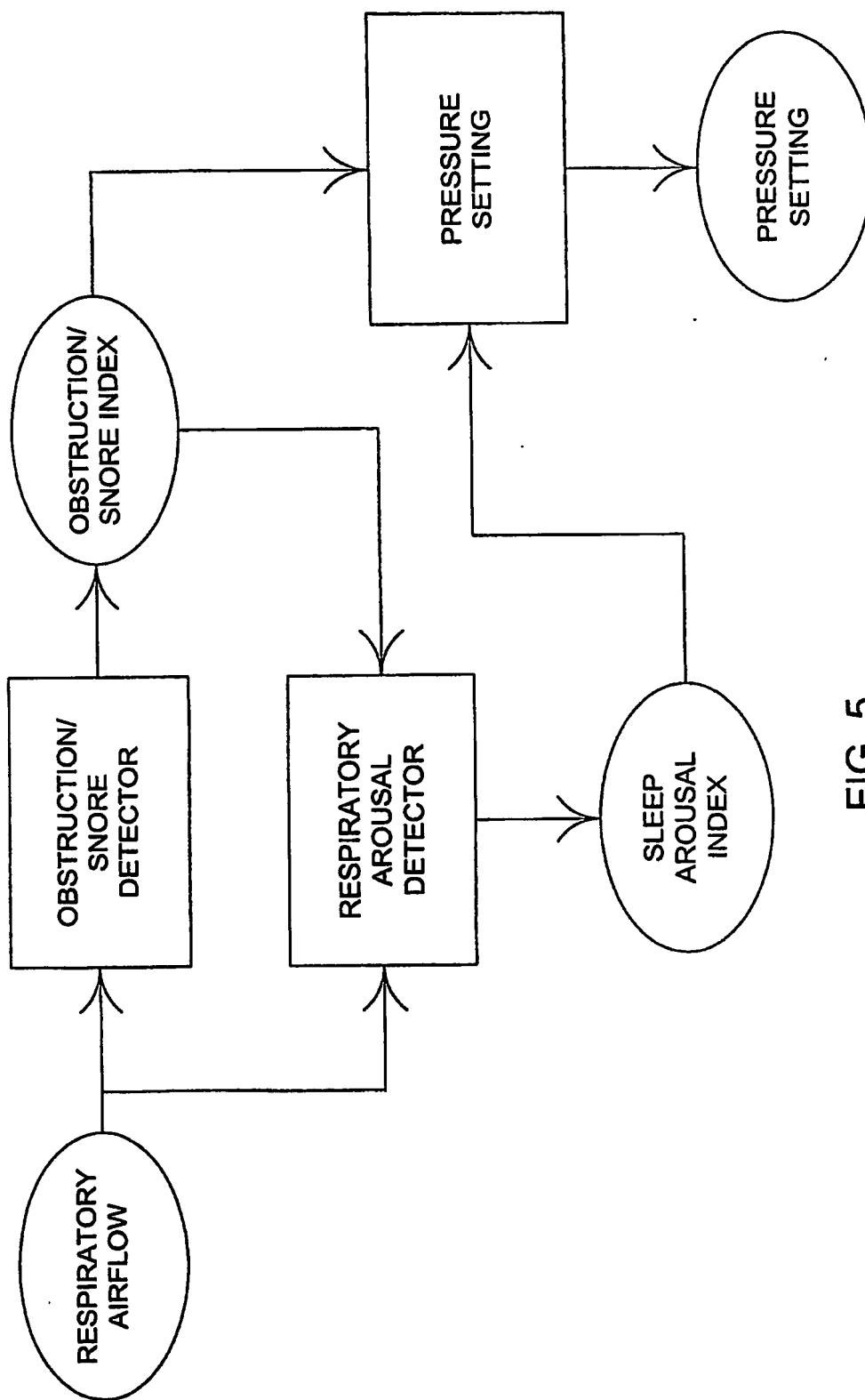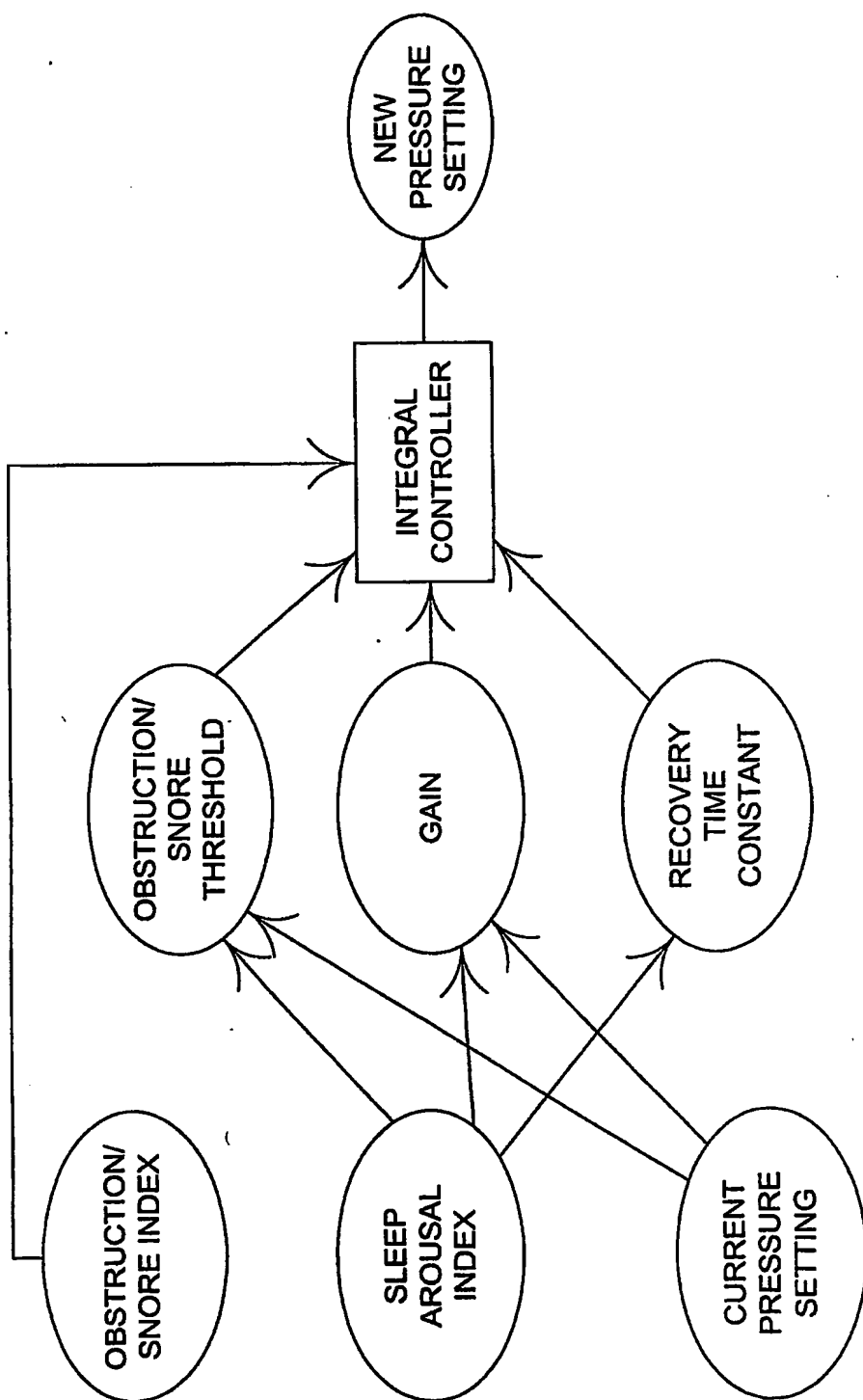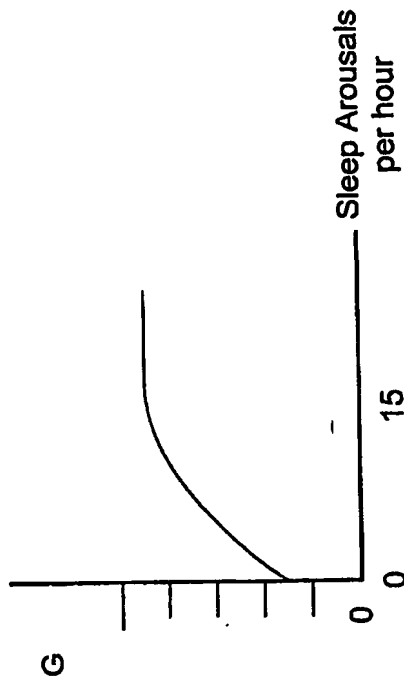relatively or absolutely large breath (n)

FIG. 4

FIG. 5

FIG. 6

G

Sleep Arousals
per hour

0   15

Fig. 8

K

Sleep Arousals
per hour

0   15

Fig. 7

S_T

Sleep Arousals
per hour

0   15

Fig. 10

S_T

Sleep Arousals
per hour

0   15

Fig. 9

S_T

0.15

Treatment
Pressure
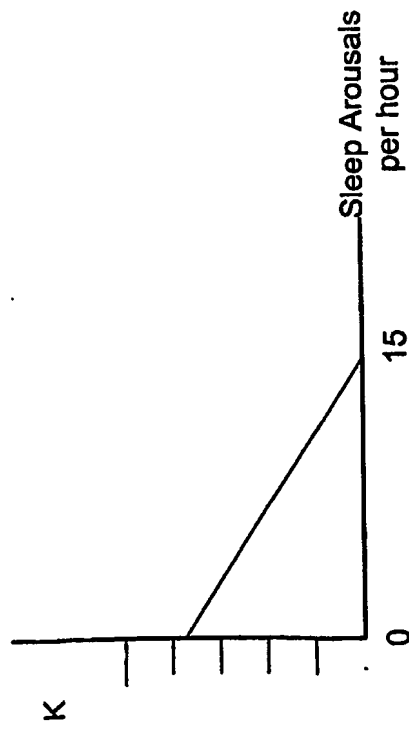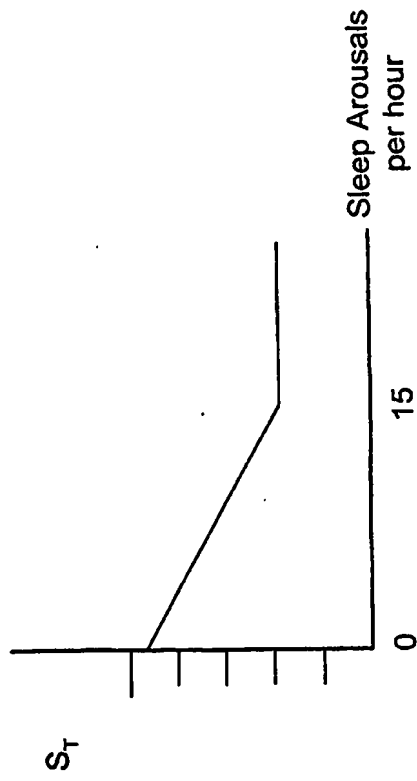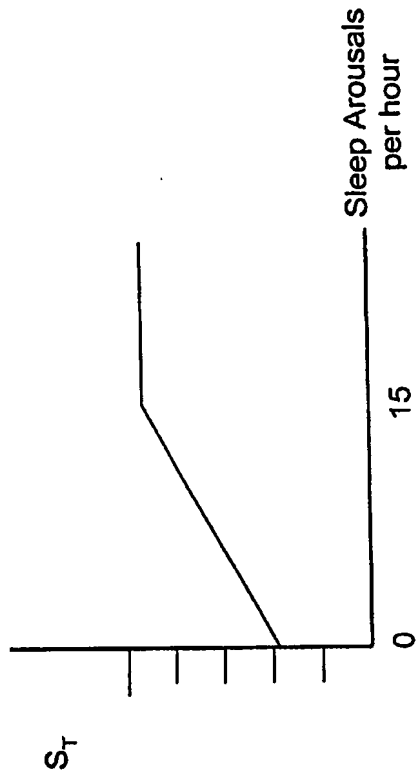
0   10   20
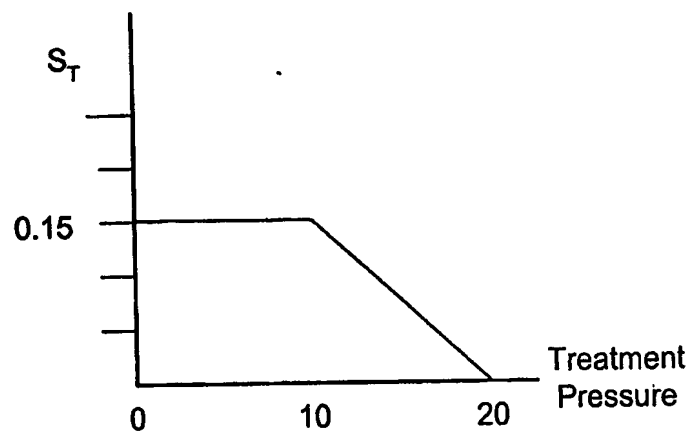
Fig. 11

Document made available under the Patent Cooperation Treaty (PCT)

International application number: PCT/AU04/001652

International filing date: 25 November 2004 (25.11.2004)

Document type: Certified copy of priority document

Document details: Country/Office: US
Number: 60/525,405
Filing date: 26 November 2003 (26.11.2003)

Date of receipt at the International Bureau: 17 January 2005 (17.01.2005)

Remark: Priority document submitted or transmitted to the International Bureau in compliance with Rule 17.1(a) or (b)